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A COMPARATIVE STUDY OF THREE METHODS OF MEASURING WEAK AND FLAT FEET

Submitted by

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degree of Master of Education

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A COMPARATIVE STUDY OF THREE METHODS OF MEASURING FLAT AND WEAK FEET

A Study Undertaken For The Purpose Of Considering The Three Most Commonly Used Methods Of Measuring Weak And Flat Feet And Determining The Practicability Of The Use Of The Pedorule For Measuring The Degree Of Flatfootedness.

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PART I

MECHANICS OF THE FOOT

CHAPTER I

INTRODUCTION

Next to carious teeth the most common and widely spread form of physical impairment among the civilized people of today are disorders of the feet. According to Bancroft[1], from fifty-seven to sixty-one per cent of the cases of flat feet are found between the ages of ten to twenty-five, which shows that young people need especial care for the hygiene of the foot during the time when the neuro-muscular system is immature, and weight is rapidly increased.

Stafford[2] found in examinations of school groups and army recruits that the per cent having true flat feet or sunken arches will average from six to thirteen while those having weak (but not flat feet) will average from seventy-three to seventy-eight per cent.

These statements are evidence enough that there exists a real problem for both the physician and the physical educator in their corrective work not only in the actual building up of weak and fallen arches but in the prevention of such cases. The appalling angle to the situation is that instead of the number of cases decreasing the percentage is growing rapidly higher and higher.

[1] Bancroft, Jessie H. The Posture of School Children, 1925.
[2] Stafford, Geo. T. Preventive and Corrective Physical Education, 1925.

Since the purpose of this study is not to determine the why of flat or weak feet but to discover a means of determining and measuring them we must describe and experiment with the methods most commonly used in order to find the one most valid, most reliable, most objective and most economical from the view-point of the physical educator.

In order that the reader appreciate to the fullest extent the criteria of a good measure for foot conditions, he must first have a general knowledge of the mechanics of the normal foot. To say that the foot consists of twenty-six bones, held together by so many ligaments and controlled by a certain number of muscles, means absolutely nothing to one who does not have a mental picture of the structure of this part. Chapter II has been devoted to Structure of the Foot. Chapter III is a description of the muscles of the foot. Chapter four deals with the joints and ligaments and Chapter five with the arches of the foot.

CHAPTER II

STRUCTURE OF THE FOOT

The skeleton of the foot consists of three parts: the tarsus, metatarsus, and phalanges.

THE TARSUS

The bones of the foot are twenty-six in number with the seven rear ones classified as the tarsal bones. They are, the calcaneus, talus, cuboid, scaphoid, and the first, second, and third cuneiforms. (See Illustration 1)

The Calcaneus

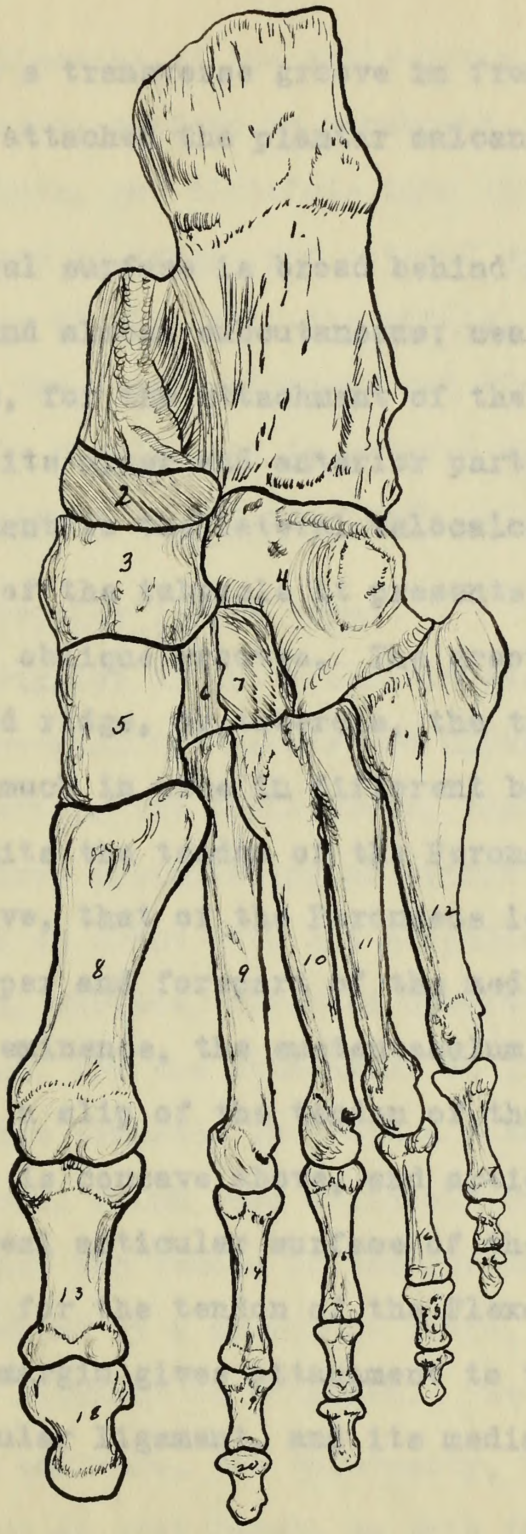
The calcaneus is the largest of the tarsal bones. It is situated at the lower and back part of the foot, serving to transmit the weight of the body to the ground, and forming a strong lever for the muscles of the calf. It is irregularly cuboidal in form, having its long axis directed forward and lateralward.

The facet, in front and to the medial side of the calcaneal sulcus, is frequently divided into two by a notch: of the two, the posterior, and larger is termed the middle articular surface; it is supported on a projecting process of bone, the sustentaculum tali, and articulated with the

middle calcaneal facet on the under surface of the astragalus (talus); the anterior articular surface of the calcaneus is placed on the anterior part of the body, and articulates with the anterior calcaneal facet on the astragalus. The upper surface, anterior and lateral to the facets, is rough for the attachment of ligaments and for the origin of the Extensor digitorum brevis.

The inferior or plantar surface is uneven, wider behind than in front, and convex from side to side; it is bounded posteriorly by a transverse elevation, the calcaneal tuberosity, which is depressed in the middle and prolonged at either end into a process; the lateral process, small, prominent, and rounded, gives origin to part of the abductor digiti quinti; the medial process, broader and longer, gives attachment, by its prominent medial margin, to the Abductor hallucis, and in front to the Flexor digitorum brevis and the plantar aponeurosis; the depression between the processes gives origin to the Abductor digiti quinti. The rough surfaces in front of the processes gives attachment to the long plantar ligament, and to the lateral head of the Quadratus plantae; while to a prominent tubercle nearer the anterior part of this surface,

PLANTAR ASPECT



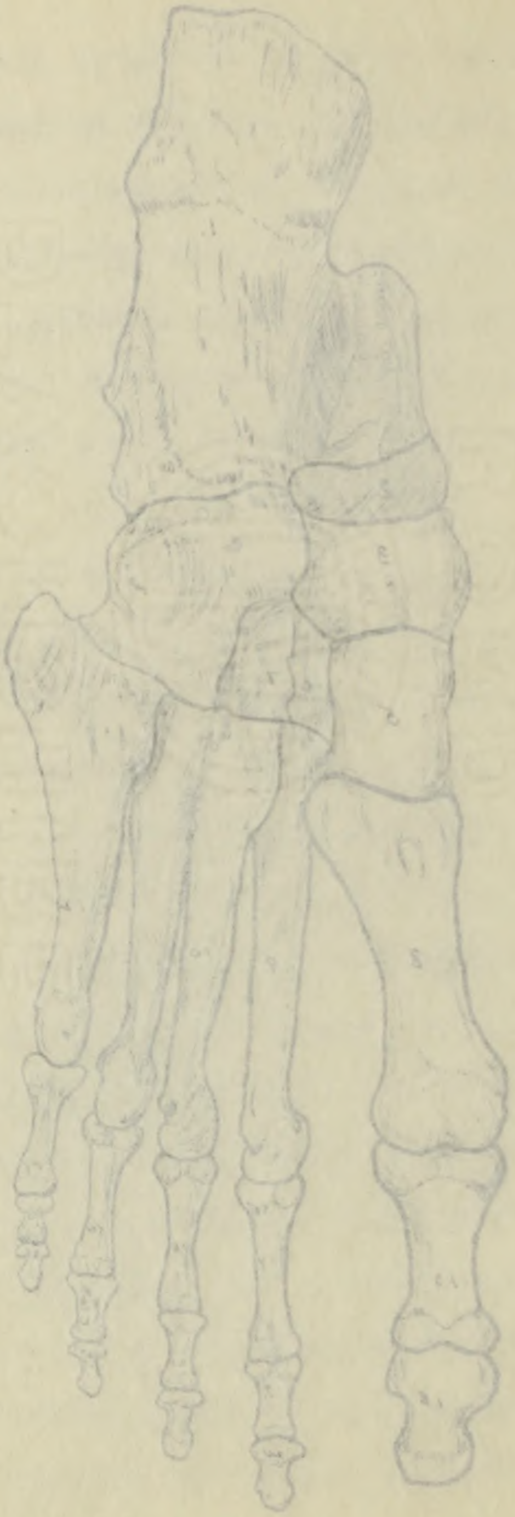
1. Calcaneus
2. Astragalus
3. Scaphoid
4. Cuboid

5-6-7 Cuneiforms

8-12 Metatarsals

13-26 Phalanges

Illustration 1



as well as to a transverse groove in front of the tubercle, is attached the plantar calcaneocuboid ligament.

The lateral surface is broad behind and narrow in front, flat and almost subcutaneous; near its center is a tubercle, for the attachment of the calcaneofibular ligament. At its upper and anterior part, this surface gives attachment to the lateral talocalcaneal ligament; and in front of the tubercle it presents a narrow surface marked by two oblique grooves. The grooves are separated by an elevated ridge, or tubercle, the trochlear process, which varies much in size in different bones. The superior groove transmits the tendon of the Peronaeus brevis; the inferior groove, that of the Peronaeus longus.

At the upper and forepart of the medial surface is a horizontal eminence, the sustentaculum tali, which gives attachment to a slip of the tendon of the Tibialis posterior. This eminence is concave above, and articulates with the middle calcaneal articular surface of the talus; below, it is grooved for the tendon of the Flexor hallucis longus; its anterior margin gives attachment to the plantar calcaneonavicular ligament, and its medial, to a part of

the deltoid ligament of the ankle-joint.

The posterior surface is prominent, convex, wider below than above, and divisible into three areas. The lowest of these is rough, and covered by the fatty and fibrous tissue of the heel; the middle, also rough, gives insertion to the tendo calcaneus and Plantaris; while the highest is smooth, and is covered by a bursa which intervenes between it and the tendo calcaneus.

The Astragalus (Ankle bone)

The astragalus is the second largest of the tarsal bones. It occupies the middle and upper part of the tarsus, supporting the tibia above, resting upon the calcaneus below, articulating on either side with the malleoli, and in front with the scaphoid..

The dorsal surface, directed upward and lateralward, is rough, for the attachment of ligaments. The plantar surface presents in front a deep groove, the peroneal sulcus, which runs obliquely forward and medialward; it lodges the tendon of the Peronaeus longus, and is bounded behind by a prominent ridge, to which the long plantar ligament is attached. The ridge ends laterally in an eminence, the tuberosity, the surface of which presents an oval facet; on this facet glides the

sesamoid bone or cartilage frequently found in the tendon of the Peronaeus longus. The surface of bone behind the groove is rough, for the attachment of the plantar calcaneocuboid ligament, a few fibers of the Flexor hallucis brevis, and a fasciculus from the tendon of the Tibialis posterior. The lateral surface presents a deep notch formed by the commencement of the peroneal sulcus. The posterior surface is smooth, triangular, and concavo-convex, for articulation with the anterior surface of the calcaneus; its infero-medial angle projects backward as a process which underlies and supports the anterior end of the calcaneus; its size is greater than that of the anterior surface. The anterior surface, also irregularly triangular, is divided by a vertical ridge into two facets; the medial, quadrilateral in form, articulates with the first. The medial surface is broad, irregularly quadrilateral and presents at its middle and upper part a smooth oval facet for articulation with the scaphoid; it is rough in the rest of its extent, for the attachment of strong interosseous ligaments.

The Scaphoid

The scaphoid bone is situated at the medial side of the tarsus, between the talus behind and the cuneiform bones in front.

The navicular (scaphoid) articulates with four bones; the astragalus and three cuneiforms; occasionally with a fifth, the cuboid.

The First Cuneiform Bone

The first cuneiform bone is the largest of the three cuneiforms. It is situated at the medial side of the foot, between the scaphoid behind and the base of the first of the metatarsals in front.

The first cuneiform articulates with four bones: the scaphoid, second cuneiform, and first and second metatarsals.

The Second Cuneiform Bone

The second cuneiform bone, the smallest of the three, is of very regular wedge-like form, the fin end being directed downward. It is situated between the other two cuneiforms, and articulates with the scaphoid behind, and the second metatarsal in front.

The second cuneiform articulates with four bones:

the scaphoid, first and third cuneiform, and second metatarsal.

The Third Cuneiform Bone

The third cuneiform bone, intermediate in size between the two preceding, is wedge-shaped, the base being uppermost. It occupies the center of the front row of the tarsal bones, between the second cuneiform medially, the cuboid laterally, the scaphoid behind, and the third metatarsal in front.

The third cuneiform articulates with six bones: the scaphoid, second cuneiform, cuboid, and second, third, and fourth metatarsals.

THE METATARSUS

The metatarsus consists of five bones which are numbered from the medial side; each presents for examination a body and two extremities.

The common characteristics of the metatarsal bones.

The body is prismoid in form, tapers gradually from the tarsal to the phalangeal extremity, and is curved longitudinally, so as to be concave below, slightly convex above. The base or posterior extremity is wedge-shaped, articulating proximally with the tarsal bones,

and by its sides with the contiguous metatarsal bones: its dorsal and plantar surfaces are rough for the attachment of ligaments. The head or anterior extremity presents a convex articular surface, oblong from above downward, and extending farther backward below than above. Its sides are flattened, and on each is a depression, surmounted by a tubercle, for ligamentous attachment. Its plantar surface is grooved antero-posteriorly for the passage of the Flexor tendons, and marked on either side by an articular eminence continuous with the terminal articular surface.

The base of each metatarsal bone articulates with one or more of the tarsal bones, and the head with one of the first row of phalanges. The first metatarsal articulates with the first cuneiform, the second with all three cuneiforms, the third with the third cuneiform, the fourth with the third cuneiform and the cuboid, and the fifth with the cuboid.

THE PHALANGES OF THE FOOT

The phalanges of the foot correspond, in number and general arrangement, with those of the hand; there are two in the great toe, and three in each of the other toes. They differ from them, however, in their size,

the bodies being much reduced in length, and especially in the first row, laterally compressed.

The First Row

The body of each is compressed from side to side, convex above, concave below. The base is concave; and the head presents trochlear surface for articulation with the second phalanx.

The Second Row

The phalanges of the second row are remarkably small and short, but rather broader than those of the first row.

The ungual phalanges, in form, resemble those of the fingers; but they are smaller and are flattened from above downward; each presents a broad base for articulation with the corresponding bone of the second row, and an expanded distal extremity for the support of the nail end of the toe.

In the second, third, fourth, and fifth toes the phalanges of the first row articulate behind with the metatarsal bones, and in front with the second phalanges, which in their turn articulate with the first and third: the ungual phalanges articulate with the second.

CHAPTER III

THE MUSCLES OF THE FOOT

The plantar fascia or aponeurosis is a dense sheet of connective tissue lying immediately beneath the skin of the plantar surface of the foot and covering the preaxial muscles. It is attached behind to the tuberosity of the calcaneum, and extends distally in a fan-like manner to be attached by five processes to the skin over the metatarso-phalangeal joints of the digits. The aponeurosis is much thicker in its middle portion than at the sides, where it is continued dorsally over the sides of the foot to become continuous with the fascia of the dorsum of the foot and with the crural fascia. Between its cutaneous insertions transverse bands of fibres stretch across to form the superficial transverse metatarsal ligament; from its deep surface strong sheets are given off which pass to the sheaths of the flexor tendons. Expansions are also given off from its deep surface which invest the flexor brevis digitorum and, on either side, the abductor hallucis and abductor minimi digiti.

Between the aponeurosis and the integument over the inferior surface of the tuberosity of the calcaneum a bursa is constantly present.

The dorsal surface of the foot is covered by the fascia dorsalis pedis, a rather thin sheet continuous with the crural fascia above. It covers the long extensor tendons.

THE PRE-AXIAL MUSCLES

Like the pre-axial muscles of the hand, those of the foot may be regarded as derived from five promary layers, which have undergone a considerable amount of modification, including some fusion.

The Muscles of the First Layer

I. Flexor brevis digitorum.	3. Abductor hallucis.
2. Flexor brevis hallucis.	4. Abductor minimi digiti.

1. Flexor Brevis Digitorum--Attachments

The short flexor of the toes arises from the inner process of the calcaneal tuberosity and from the plantar aponeurosis. It extends distally, beneath the aponeurosis,

as a thick quadrangular muscle, the fibres of which are collected over the metatarsal bones into four tendons, which pass to the second, third, fourth and fifth toes. Over the first phalanx of the toe each tendon divides into two terminal slips, between which the corresponding tendon of the flexor longus digitorum passes and which are inserted into the second phalanx.

ACTION

To flex the second, third, fourth, and fifth toes.

VARIATIONS

The most frequent variation in this muscle is the absence of the tendon to the fifth toe, an absence which occurs in somewhat over twenty-one per cent of cases examined. Sometimes the tendon is replaced by a slip or muscle which arises from the flexor longus digitorum.

The flexor brevis represents the middle portion of the superficial flexor layer, and corresponds, accordingly, to the terminal portions of the tendons of the flexor sublimis of the hand. Its origin is primarily from the plantar aponeurosis, and hence the occasional origin of the portion for the fifth toe becomes

intelligible, since the tendon of the flexor longus is a differentiation of the deeper layer of the aponeurosis.

2. Flexor Brevis Hallucis--Attachments

The short flexor of the great toe arises from the plantar surface of the internal cuneiform bone and the adjacent ligamentous structures. Its fibres pass distally to a tendon which contains a sesamoid bone, and is inserted into the inner surface of the base of the first phalanx of the great toe.

ACTION

To flex the great toe.

VARIATIONS

The flexor brevis hallucis is frequently intimately fused with the abductor hallucis.

A portion of the deeper fibres of the flexor brevis hallucis is frequently inserted into the whole length of the first metatarsal. Occasionally these fibres are quite distinct from the rest of the muscle, forming what has been termed an opponens hallucis.

In the description of the muscle given above, account has been taken only of what is usually described as the inner portion, the flexor brevis pollicis being usually

regarded as consisting of two bellies, the second of which inserted into the lateral side of the base of the first phalanx of the great toe. The relations of this outer belly and its nerve-supply, however, indicate that it belongs to an entirely different layer than the medial belly. It will, therefore, be considered later in connection with the interossei.

3. Abductor Hallucis--Attachments

The abductor hallucis extends along the inner border of the foot, arising from the inner tubercle, and surface of the calcaneum and from the plantar aponeurosis and being inserted, along with the flexor brevis hallucis, into the inner side of the base of the first phalanx of the great toe.

ACTION

To abduct and flex the hallux.

4. Abductor Minimi Digiti--Attachments

The abductor of the little toe is situated along the outer border of the foot. It arises from the under surface of the calcaneum and from the plantar aponeurosis, and extends distally and laterally to be inserted partly into the tuberosity of the fifth metatarsal bone and partly

into the lateral side of the base of the first phalanx of the little toe.

ACTION

To abduct and flex the little toe.

VARIATIONS

A portion of the abductor digiti quinti frequently separates from the rest of the muscle to form a fusiform belly which has been termed the abductor ossis metatarsi quinti. It arises from the lateral part of the inferior surface of the os calcis and is inserted either independently or in common with the abductor, into the tuberosity of the fifth metatarsal.

The Muscle of the Second Layer

Lumbricales--Attachments

The lumbricales are four spindle-shaped muscles which arise from adjacent borders of the tendons of the flexor longus digitorum and from the inner border of its first tendon. They pass distally to the inner surfaces of the first phalanges of the second, third, fourth, and fifth digits, where they are inserted into the membranous expansion of the tendons of the extensor longus digitorum.

ACTION

To flex and draw medially the second, third, fourth, and fifth toes.

VARIATIONS

Absence of one or other of the lumbricales has been noted, the fourth and third being those most frequently lacking; these same muscles are frequently bifid at their insertions. Small bursa may intervene between the tendons and the first phalanges.

The significance of the lumbricales is similar to that of the corresponding muscles of the hand. They arise primarily from the deeper layers of the plantar aponeurosis, and when these differentiate into tendons of the flexor longus digitorum they come to arise from those structures.

The Muscle of the Third Layer

Adductor Hallucis--Attachments

The adductor hallucis consists of two portions, often described as two distinct muscles, united only at their insertions. The oblique portion, or adductor obliquus, arises from the base of the second, third, and fourth metatarsals and from the long plantar ligament and passes

distally and inward along the interval between the first and second metatarsals, its fibres converging to a strong tendon which unites with that of the transverse portion, or adductor transversus. This extends almost transversely, under cover of the three medial tendons of the long and short flexors and lumbricales, over the heads of the fourth, third, and second metatarsals. It arises from the capsules of the four lateral metatarso-phalangeal joints and passes medially to join the tendon of the first plantar interosseous and is inserted into the sesamoid bone of that tendon and into the lateral surface of the base of the first phalanx of the great toe.

ACTION

To flex and adduct the hallux.

VARIATIONS

Some variation occurs in the extent of the origin of both portions of the adductor hallucis. The oblique portion may be limited to the long plantar ligament, or may receive an accessory slip from the shaft of the second metatarsal, while the origin of the transverse

portion from the fifth metatarso-phalangeal joint may be lacking.

It is to be noted that in the foetus the two portions of the adductor are not separated by a wide interval as in the adult, but lie in contact with each other.

A small muscular slip has occasionally been observed passing from the long plantar ligament to the surface of the base of the first phalanx of the second toe. It appears to represent the adductor secundi digiti.

The Muscles of the Fourth and Fifth Layers

I. Interossei plantares. 3. Flexor brevis minimi digiti.
2. Interossei dorsales.

1. Interossei Plantares--Attachments

The plantar interossei are four spindle-shaped muscles. The first is very much stronger than the others, and is often described as the outer head of the flexor brevis hallucis. It arises in common with the flexor brevis hallucis, from the inner cuneiform bones and the adjacent ligamentous structures. It extends distally along the lateral surface of the first metatarsal bone and passes

over the strong tendon, which contains a sesamoid bone, and is inserted into the outer surface of the base of the first phalanx of the great toe, along with the adductor hallucis.

The remaining three muscles are much smaller and arise in succession from the medial surfaces of the third, fourth, and fifth metatarsals, and, passing distally, are inserted by slender tendons into the membranous expansions of the long extensor tendons of the third, fourth, and fifth toes, on the medial sides of their first phalanges.

ACTION

To flex the first, third, fourth, and fifth toes, and draw the last three medially.

VARIATIONS

As above stated, the first plantar interosseus is usually described as a second head of the flexor brevis hallucis. It is sometimes more or less inseparable from the oblique portion of the adductor hallucis.

2. Interossei Dorsales--Attachments

The dorsal interossei are also four in number. They arise from the adjacent sides of each pair of metatarsals and pass distally in the interspaces between these bones.

The fibres of each muscle converge to a narrow tendon which is inserted into the membranous expansions of the extensor tendons over the first phalanges of the second, third, and fourth toes. The first and second muscles insert into the opposite sides of the second toe and the third and fourth toes.

ACTION

To flex the second, third, and fourth toes; the first also draws the second toe medially and the rest the second, third, and fourth toes laterally.

3. Flexor Brevis Minimi Digiti--Attachments

The short flexor of the little toe, which really represents the fifth plantar interosseus, arises from the base of the fifth metatarsal and passes distally along the outer side of the fourth plantar interosseus to be inserted by a tendon into the outer surface of the base of the first phalanx of the fifth toe and also into the distal portion of the fifth metatarsal.

ACTION

To flex the fifth toe and draw it lateralward.

VARIATIONS

The portion of the flexor brevis minimi digiti which

passes to the fifth metatarsal is frequently more or less distinct from the rest of the muscle, and has then been termed the opponens quinti digiti.

THE POST-AXIAL MUSCLE

Extensor Brevis Digitorum--Attachments

The short extensor of the toes arises from the lateral and superior surfaces of the calcaneum. It passes distally beneath the tendons of the extensor longus digitorum and divides into four portions, the outer three of which become tendonous and are inserted by fusing with the tendons of the extensor longus to the second, third, and fourth toes over the first phalanges of those toes; the innermost tendon is inserted into the base of the first phalanx of the great toe.

ACTION

To extend and draw laterally the first, second, third, and fourth toes.

VARIATIONS

Occasionally one or other of the tendons of the extensor brevis may be doubled, this condition being most frequent in the tendon of the second toe; sometimes a fifth tendon passes to the little toe.

The innermost tendon is nearly always much stronger than the others; the fibres which insert into it are occasionally separate from the remainder of the muscles,, then forming the extensor brevis hallucis.

CHAPTER IV

THE JOINTS AND LIGAMENTS OF THE FOOT

The joints and ligaments of the foot will be considered separately, since many of the ligaments of the foot belong to several joints.

THE JOINTS OF THE FOOT

The joints between the talus and the bones of the leg and those between the individual bones of the foot may be divided into the following groups:

1. The articulation of the Talus, which include the talo-crural articulation (the ankle joint), the talo-calcaneal articulation, the talocaneo-scaphoid articulation, and the calcaneocuboid articulation.
2. The tarsal arthrodia.
    (a) The intertarsal articulations (the cuneo-scaphoid articulation).
    (b) The tarsometatarsal joints (the tarsalmetatarsal and intermetatarsal articulations).
3. The joints of the toes (the metatarsophalanges and digital (interphalangeal) articulations).

The ankle-joint or talocrural articulation is the joint between the astragalus and the two bones of the leg. The articulating surfaces are the trochlea of the talus upon the one hand,, and the inferior articular surface of the tibia and the articular surfaces of the internal and external malleoli upon the other.

The articular capsule, which surrounds the cartilaginous surfaces and is inserted toward the neck of the astragalus, is thin; its anterior and especially its lateral portions are rather tense, while the posterior portion is roomy and relaxed.

From its function and in accordance with the form of the articular surfaces, the talocrural articulation is a huge joint, the socket of which, however, is formed by two bones. As the syndesmosis connecting the tibia and the fibula does not absolutely preclude motion, the broad anterior portion of the trochlea of the talus can be accomodated by a slight separation of the bones of the leg; and when the foot is depressed, the narrow posterior portion of the trochlea has so much room in the articular socket that slight lateral movements are possible in the axis of the fibula. The ankle joint is consequently not a pure hinge joint, although it acts

mainly as such; its movements are those of plantar and dorsal flexion.

The talocalcaneal articulation is the joint between the convex posterior articular surface of the calcaneus and the concave posterior calcaneal articular surface of the talus. The articulating facets are portions of the surface of a cone, the axis of which is almost sagittal, but directed somewhat obliquely upward and forward. The articular capsule is roomy and relaxed. This articulation occasionally communicates with the ankle joint.

The talocalcaneo-scaphoid articulation is the joint formed by the head of the talus, the anterior and middle articular facets of the calcaneus, the posterior articular facet of the scaphoid, and the scaphoid fibro-cartilage of the plantar calcaneo-scaphoid ligament. The joint is a pronouncedly compound articulation, and includes an anterior talocalcaneal and a taloscaphoid articulation. The socket for the head of the talus is formed by four different cartilage-covered surfaces. The articulation is separated from the posterior calcaneo-astragaloid joint by the sinus of the tarsus and its articular capsule exhibits no special peculiarities.

The calcaneocuboid articulation is the joint between the cuboid articular surface of the calcaneus and the posterior articular surface of the cuboid bone. The surfaces are approximately saddle-shaped. Together with the taloscaphoid joint it forms a transverse articulation of the tarsus.

From the functional standpoint the talocalcaneo-scaphoid joint is composed of two portions. The first of these is the joint between the talus and the scaphoid bone, which acts together with the calcaneo-cuboid articulation. It is an ellipsodial joint, while the taloscaphoid articulation is a saddle-joint. Although these joints are biaxial, they check each other reciprocally, so that during motion each joint loses one of its axes of movement and a common uniaxial hinge joint results, the transverse tarsal joint. The remaining portion of the talocalcaneo-scaphoid joint act together with the talocalcaneal joint, whose axis coincides with that of the transverse tarsal joint. Both joints, or rather both combinations of joints, always work together; during adduction there is also an elevation of the inner margin of the sole of the foot (supination), and during

adduction there is a simultaneous elevation of the other margin of the sole of the foot (pronation). The anatomical and physiological associations of the joints are altogether different, as is also the case at the elbow and at the inferior radio-ulnar articulations.

The arthrodia of the tarsus consist of a variable number of single or combined articulations, since neighboring articular cavities frequently intercommunicate, and while the number of articular facets is relatively large, the number of joints is comparatively small because the small lateral articular facets do not all form independent articulations.

The cuneo-scaphoid articulation is the joint between the articular surface of the scaphoid bone and the posterior articular facets of the three cuneiform bones; it also extends between the opposed articular facets of the cuneiform bones and between the internal articular surface of the cuboid and the corresponding surfaces of the scaphoid and external cuneiform bones. The joint also usually communicates between the internal and middle cuneiform bones with the second tarsometatarsal joint, and is consequently a very complicated articulation.

The tarso-metatarsal articulation (Lisfranc's Joint) together with the intermetatarsal articulations, form three separate joints: one connecting the metatarsal bone of the great toe with the internal cuneiform bone; one connecting the bases of the second and third metatarsal bones with each other and with the middle and external cuneiform bones; and the third connecting the fourth and fifth metatarsal bones with the cuboid bone. The line of Lisfranc's joint has its proximal point at the inner margin of the sole of the foot and its most distal point at the base of the second metatarsal bone, so that a deep indentation is present in this situation. From this point the joint-line pursues a markedly distal direction and then makes a distinct curve toward the proximal portion of the foot.

The movements in the tarsal arthrodia are extremely slight, since numerous tense ligaments limit the range of motion considerably. The slight movements which are possible supplement the chief movements of the foot.

The metatarso-phalangeal and the digital (inter-phalangeal) joints resemble the corresponding joints of the hand with slight variations. The metatarso-phalangeal joint of the great toe in particular exhibits a special mechanism, as two large sesamoid bones are imbedded in

the plantar surface of the capsular ligament and transform the articulation into a species of hinge joint. A further peculiarity is the marked dorsal extension of the articular surfaces, particularly those of the second to the fifth metatarsal bones, which permit of a hyperextension (dorsal flexion) of the toes. These articulations also resemble hinge joints more than arthrodia. Ossification is frequently observed between the individual phalanges, particularly in the little toe. The accessory ligaments of these joints are similar to those of the hand.

The Ligaments of the Tarsus

The ligaments of the tarsus may be subdivided into: (1) The ligaments of the ankle-joint, (2) The ligaments between the astragalus and the calcaneus, (3) The dorsal tarsal ligaments, (4) The plantar tarsal ligaments, and (5) The interosseous tarsal ligaments.

The ligaments of the ankle-joint connect the bones of the leg with the talus and the calcaneus, and pursue a more or less vertical direction. Each of the two malleoli is connected with the neighboring tarsal bones. The deltoid ligament arises from the internal malleolus

and radiates to the talus, the calcaneus, and the scaphoid bones. It is narrower at its origin, broad at its insertion, and is composed of four separate ligaments: the anterior talo-tibial, the posterior talo-tibial, the calcaneo-tibial, and the tibio-scaphoid ligaments.

The anterior talo-tibial ligament passes to the anterior extremity of the neck of the talus and is almost completely covered by the calcaneo-tibial ligament which runs to the margin of the sustentaculum tali. The posterior talo-tibial ligament goes to the posterior process of the talus, and the tibio-scaphoid has its insertion upon the dorsal surface of the scaphoid bone.

Ligaments pass in a similar manner from the external malleolus to the talus and to the calcaneus. These are known as the anterior talo-fibular, the posterior talo-fibular, and the calcaneo-fibular ligaments. The anterior talo-fibular ligament passes almost horizontally from the anterior surface of the external malleolus to the anterior margin of the trochlea of the talus; the posterior talo-fibular pursues a corresponding course and connects the posterior border of the external malleolus with the outer tubercle of the posterior process of the talus; and the calcaneo-fibular ligament passes somewhat obliquely down-

ward and backward from the tip of the external malleolus to the outer surface of the calcaneus. Upon this ligament run the tendons of the two peroneal muscles.

The ligamentous connections between the astragalus and the calcaneus consist of the reinforcing ligaments of the talo-calcaneal articulation and of the ligamentous mass which occupies the sinus of the tarsus, the interosseous talo-calcaneal ligament. The latter consists of a number of firm fibrous layers and forms a species of syndesmosis between the two bones.

The reinforcing ligaments of the posterior articulation of the two bones are known as the internal, external, posterior, and anterior talo-calcaneal ligaments. The external and particularly the anterior ligaments, which bridge over the sinus of the tarsus, are connected with the interosseous ligament. The external ligament from the outer and lower surface of the neck of the talus (astragalus) to the upper surface of the calcaneus; the anterior ligament connects the lower surface of the talus with the upper surface of the calcaneus; the posterior ligament connects the outer tubercle of the posterior process of the talus with the upper surface of the calcaneus; and

the very narrow internal ligament passes from the inner tubercle of the posterior process of the talus to the sustentaculum tali.

The dorsal and plantar ligaments of the foot are practically horizontal, and are composed partly of transverse and partly of longitudinal fasciculi which connect neighboring bones and consequently reinforce the articular capsules. The plantar ligaments are considerably the stronger, and some of them connect distant portions of the tarsus, passing over one or even more bones.

The dorsal tarsal ligaments are those, which connect the talus and the calcaneus with the scaphoid and the cuboid bones. They are the dorsal talo-scaphoid ligament, the dorsal calcaneo-scaphoid ligament, and the bifurcate ligament. The bifurcate ligament connects the antero-internal angle of the calcaneus with the dorsal surfaces of the scaphoid and cuboid bones; it necessarily divides into two portions, one for each bone, known as the calcaneo-scaphoid and the calcaneo-cuboid portions.

The scaphoid is connected with the cuneiform bones by the three dorsal scaphoid-cuneiform ligaments. The first of these is the broadest. The cuboid and scaphoid bones

are connected by the dorsal cuboideo-scaphoid ligaments; the cuneiform bones are connected with each other by the dorsal intercuneiform ligaments; and the dorsal cuneo-cuboid ligament runs between the external cuneiform and cuboid bones.

The connection between the bases of the metatarsal bones and the tarsal bones is effected by the dorsal tarso-metatarsal ligaments; the bases of the metatarsals are connected with each other by the four dorsal basal ligaments.

The plantar tarsal ligaments maintain the normal arch of the foot. By far the largest and strongest of them is the long plantar ligament, which is, indeed, one of the strongest ligaments of the body. It arises from the entire lower surface of the calcaneus in front of the tubercles of the tuberosity, its width almost entirely covering the bone, and its strong longitudinal fasciculi are inserted into the tuberosity of the cuboid. From the main mass of the ligament there are given off superficial fasciculi which pass over the tendon-sheath of the peroneus longus situated in the cuboid groove, and extend to the bases of the outer metatarsal bones.

The second strongest ligament of the tarsus is the plantar calcaneo-scaphoid ligament, whose strong fibres pass obliquely between the sustentaculum tali and the scaphoid fibrocartilage which forms a portion of the socket for the head of the talus. Upon the dorsal surface of the foot this ligament is connected with the tibio-scaphoid ligament.

The plantar calcaneo-scaphoid ligament is adherent to the dorsal surface of the long plantar ligament and reinforces the plantar surface of the articular capsule of the calcaneocuboid joint. The scaphoid and the cuneiform bones are connected by the plantar scaphoid-cuneiform ligaments; the cuboid and the scaphoid bones by the plantar cuboideo-scaphoid ligament; the cuboid and the external cuneiform bones by the plantar cuneo-cuboid ligament; and the three cuneiform bones with each other by the plantar intercuneiform ligaments. There are also plantar tarso-metatarsal ligaments and three plantar basal ligaments, which pursue a similar course to the corresponding dorsal ligaments.

The interosseous ligaments are those ligaments of the foot which are situated neither upon the dorsal nor the

plantar surface, but which connect contiguous surfaces of the tarsal or metatarsal bones in those situations where no articular connection exists. They really represent syndesmosis , and are found only between those bones which move upon each other but slightly, if at all. In addition to the previously mentioned interosseous talocalcaneal ligament, these ligaments are the interosseous cuneo-cuboid ligament, the interosseous intercuneiform ligaments, the interosseous cuneo-metatarsal ligaments, and the interosseous basal metatarsal ligaments. The upper and lower surfaces of some of these ligaments are in direct contact with the corresponding dorsal and plantar ligaments.

Harvey, B. C. H. Simple Lessons in Human Anatomy American Medical Association,, Chicago, 1931

Williams, Jesse Feiring A Text Book of Anatomy and Physiology, W. B. Saunders and Company, Philadelphia: 1932

CHAPTER V

ARCHES OF THE FOOT

The normal human foot might well be compared with a scientifically constructed suspension bridge. The calcaneus should be considered one pier or tower, with the heads of the metatarsals as the other. The cables holding this arch in place are the ligaments and tendons of the foot. The arch itself is composed of the tarsal and metatarsal bones. (Illustration 2.)

The two main arches are the anterior-posterior, which we shall regard as divisable into two types, a medial and a lateral. (Illustration 3.) The medial arch is composed of the calcaneus, the talus, the scaphoid, the three cuneiforms, the first, second, and third metatarsals. Its summit is at the superior articular surface of the talus, and its two extremities or piers, on which it rests in standing, are the tuberosity on the plantar surface of the calcaneus posteriorly and the heads of the first, second, and third metatarsal bones anteriorly. Because of its height and the number of small joints between its

component parts, the chief characteristic of the arch is its elasticity. The part most likely to yield to overpressure is the joint between the talus and the scaphoid, but this portion is braced by the calcaneoscaphoid ligament which is elastic and is thus able to quickly restore the arch to its pristine condition when the disturbing force is removed. The ligament is strengthened medially by blending with the deltoid ligament of the ankle joint, and is supported inferiorly by the tendon of the Tibialis posterior, which is spread out in a fan-shaped insertion and prevents undue tension of the ligament or such an amount of stretching as would permanently elongate it. The plantar aponeurosis also supports the arch, as do the small muscles in the sole of the foot, and the tendons of the Tibialis anterior and posterior and Peronaeus longus, and by the ligaments of all the articulations involved. The lateral arch is composed of the calcaneus, the cuboid, and the fourth and fifth metatarsals. Its chief joint is the calcaneocuboid which possesses a special

mechanism for locking, and allows only a limited movement. Two strong ligaments, the long plantar and the plantar calcaneocuboid together with the Extensor tendons and the short muscles of the little toe to support it.

While these medial and lateral arches may be readily demonstrated as the component anterio-posterior arches of the foot, yet the fundamental longitudinal arch is contributed to by both, and consists of the calcaneus, cuboid, third cuneiform, and third metatarsal: all the other bones of the foot may be removed without destroying this arch.

In addition to the longitudinal arches the foot presents a series of transverse arches. At the posterior part of the metatarsus and the anterior part of the tarsus the arches are complete, but in the middle of the tarsus they present more the characters of the half-domes, the concavities of which are directed downward and medialward, so that when the medial borders of the feet are placed in apposition a complete tarsal dome is formed. The transverse

arches are strengthened by the interosseous, plantar, and dorsal ligaments, by the short muscles of the first and fifth toes (especially the transverse head of the adductor hallucis), and by the peroneus longus, whose tendon stretches across between the piers of the arches.

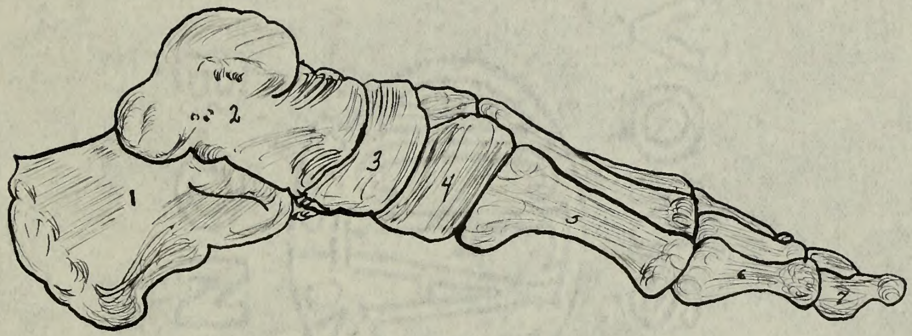


ILLUSTRATION II SKELETON OF FOOT. MEDIAL ASPECT

1. Calcaneus
2. Astragalus
3. Scaphoid
4. First Cuneiform
5. First Metatarsal
6.-7. Phalanges

PART II

THE COMPARATIVE STUDY

CHAPTER VI

METHODS OF DETERMINING POSTURE OF THE FEET

(A) Subjective estimate of examiners.

This method is doubtless the most widely used in American schools today.

The examiner judges the foot subjectively by his own particular method. The following are some of the methods used:

a. Examining the tendon of Achilles to see if it is bowed in.

b. Observing the malleoli and judging their position.

c. Observing and judging the arch itself, often by placing one or two fingers under the longitudinal arch.

Any or all combinations of the above may be used.

(B) The pedograph and other methods of measuring the ground plan of the foot.

The pedograph ranks next to the subjective judgment of examiners in popularity of use.

The pedograph is an instrument which registers footprints

The first attempt to measure footprints was made by Schwartz[1] who originated the footprint angle. This angle is the chief mathematical measure of foot conditions available from footprints. One method of scoring the footprint is shown below in Illustration 3.

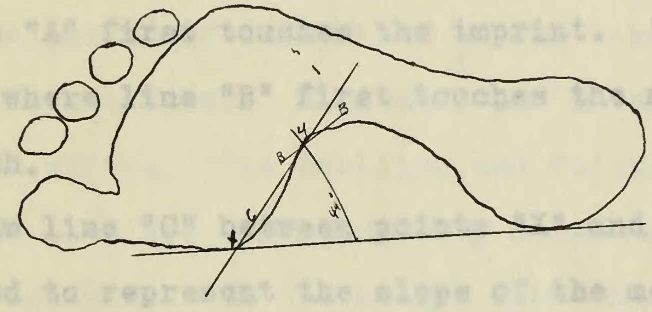


Illustration 3[2]

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1. Schwartz, Lows Britten, R. H. and Thompson, L. R. Studies in Physical Development and Posture United States Public Health Bulletin 1928 p. 23 No. 179
2. Clarke, H. Harrison An Objective Method of Measuring the height of the Longitudinal Arch in Foot Examinations The Research Quarterly, October 1933, Vol. IV No. 3.

INSTRUCTION FOR SCORING FOOTPRINTS

1. Draw line "A" to represent the medial border of the foot between the points of the imprint at the base of the first metatarsal bone and the calcaneus.

2. Draw line "B" to represent the slope of the inner segment of the longitudinal arch at its junction with the metatarsal border of the arch.

3. Locate point "X" and "Y". "X" is located at the point where line "A" first touches the imprint. "Y" is located at the point where line "B" first touches the metatarsal border of the arch.

4. Draw line "C" between points "X" and "Y". This line is intended to represent the slope of the metatarsal border of the longitudinal arch.

5. Measure the angle at the junction of the lines "A" and "C" with a protractor.

Another method of judging the ground plan of the foot is to have the subject walk barefoot on a dusty floor. If the inside of his foot at the bottom of the instep has become dusty it is a fair indication of the presence of flat foot. A variation of this plan would be to judge the print left on the dusty floor,, or have each subject slightly dampen his feet and step on the dry floor.

Still another method, known as the sand method, as used by Dr. Cureton, is where the subject leaves his footprint in wet sand. The height of the subjects arch is then measured objectively by the examiner.

(C) The Pedorule

This instrument is a rectangle of glass, seven inches wide and nine inches high, with the seven inch surface lined in tenths of inches. This pedorule was devised to measure the amount of deflection of the tendon of Achilles from the perpendicular. Williams,[1] in "A Text Book of Physical Education," states, "The swelling and fullness along the inner side of the foot are accompanied by a bending inward of the tendon of Achilles. In the normal foot the tendon of Achilles makes a straight line, but in a weak foot the lower end appears to be deflected outward."

The man who first conceived the idea of determining degrees of flat feet by objective measurement of the deviation from the perpendicular of the tendon of Achilles was Prof. C. D. Giauque of the Department of Health and Physical Education, Boston University. Carl Marx Rubin, a student at Boston University, made the first pedorule which was lined in eighths

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1. Williams, Jesse Feiring and Morrison, Whitlaw Reid
   A Text Book of Physical Education, W. B. Saunders Co.
   Philadelphia and London, 1931

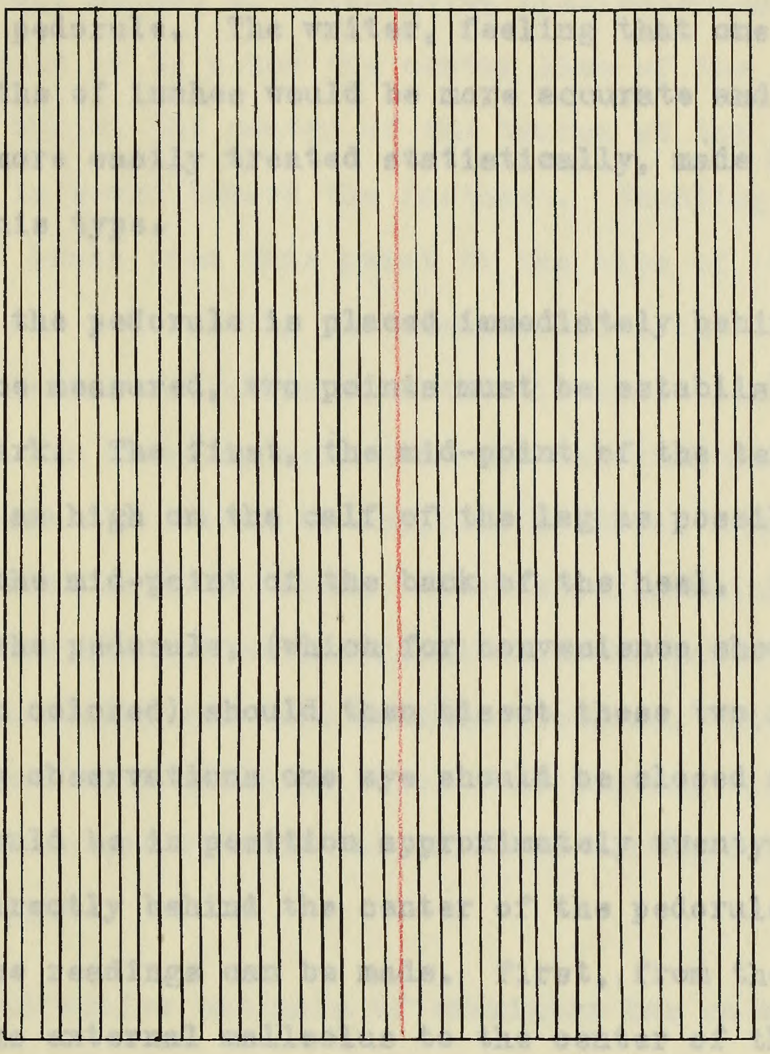

Illustration IV The Pedorule.

of inches. Mr. Rubin did not conduct any experiments with his pedorule. The writer, feeling that one divided into tenths of inches would be more accurate and the results more easily treated statistically, made and used one of this type.

When the pedorule is placed immediately behind the foot to be measured, two points must be established by an ink mark. The first, the mid-point of the tendon of Achilles as high on the calf of the leg as possible, and second, the mid-point of the back of the heel. The center line on the pedorule, (which for convenience should be larger or colored) should then bisect these two ink marks. In taking observations one eye should be closed and the other should be in position approximately twenty-four inches directly behind the center of the pedorule. From here three readings can be made. First, from the extreme tip of the external malleolus to the center of the tendon; second, from the internal malleolus to the center of the tendon; third, the distance from the center of the tendon where it is bowed in the farthest to the center line of the pedorule. The center line of the pedorule will coincide with the center line of the tendon of Achilles if the arch is neither flat nor weak.

A second method of determining flatfootedness by the pedorule is to place the center line of the pedorule directly behind the center of the tendon at the point where it is bowed inward the farthest. Counting the number of lines from this point to the tips of the malleoli and subtracting the distance from the tendon to the internal malleolus from the distance from the center of the bowed in tendon to the external malleolus, the distance the tendon of Achilles deviates from the perpendicular will be found. After experimenting with both methods the writer has found that the latter method is less confusing and more quickly recorded. The reading for a normal arch would be zero, thus showing the tendon to be equidistant between the malleoli throughout its entire length.

The subjective estimate of examiners has no norms except those in the minds of the examiners. The objectivity coefficient between experts was found by the writer to be .58. The writer believes this is fairly high as a coefficient of correlation between subjective examiners since it agrees closely with the results of an experiment performed by Franzen[1] in 1929. He averaged the correlation

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[1] Franzen, Raymond Physical Measures of Growth and Nutrition, Chapters I-III, American Child Health Ass'n.

coefficients between the judgments of physicians on the nutritional status of children and found the result to be .60. No reliability coefficient was determined. The reliability coefficient of the pedograph as computed by H. Harrison Clarke[1] was found to be .97 while the objectivity coefficient was found to be .95.

The norms for the footprint angle are as yet not well established. Schwartz[2] found that by his method the average angle was "about forty-five degrees," while Rogers[3] estimated it to be forty degrees after examining three hundred prints taken from a highly selective group of high school and college students.

There has been some question as to the validity of the footprint angle. The following is a quotation from Hygeia, September, 1932,[4] "A footprint will indicate whether or not the arch is flat, but weakness of an arch may be present even when the imprint is normal. A strong, fleshy foot may produce an imprint suggesting a flat foot."

1. Clarke, H. Harrison op. cit. p. 105
2. Schwartz, Lows Britten, R. H. and Thompson, L.R. op. cit. p.23
3. Rogers, Frederick Rand Tests and Measurement Programs in the Redirection of Physical Education, Columbia University, Bureau of Publications, 1927
4. Hygeia, September, 1932

Boston University
School of Education
Library

Williams and Morrison,[1] in their book, say, "Feet vary in their shape like other parts of the body; in some the arch is higher than in others. Occasionally the arch may be extremely high or low and still be normal. Much more important than the height of the arch is the position of the foot in relation to the leg."

The two cases described in Chapter Eight of this study proves, to the writer at least, that there are different types of feet, just as there are different types of heads, hands, noses, fingerprints, etc.

No one would say that the arch in a hand was broken down if its imprint did not conform with another. Hands are recognized as different types, such as the long, slender hands and the short, pudgy ones. So it is with feet, yet the different types have not been considered in the past when an examination was being made for flat feet.

1. Williams, Jesse Feiring and Morrison, Whitlaw Reid
   A Text Book of Physical Education W. B. Saunders Co.
   Philadelphia and London: 1931

CHAPTER VII

METHODS OF PROCEDURE

The testing for this study was carried on at the Boston University Gymnasium. The subjects were sixty in number and were the members of three physical education classes.

Great care was exercised to keep the results of each examination secret from each succeeding examiner so that in no way would he be influenced in his judgments. In order to do this to the best advantage the examiners were placed about the gymnasium twenty-five feet apart, in the following order: first,, subjective examiner number one, second, subjective examiner number two, third, the pedorule, and fourth, the pedograph. Each of the examiners, except the pedograph operator, recorded his findings, with the subjects name, on a three by five inch card. These cards were kept by each examiner and the subjects went on to the next examiner where the same procedure was followed.

The subjective examiners were asked to place each foot in one of five categories, the first group being

the perfect arch, then varying the degrees of flat feet as two, three, four, and five which was the extreme flat footed group.

The recordings of the examinations of the pedorule were made in tenths of inches. The reading of zero on the pedorule signified a perfectly perpendicular tendon of Achilles and a normal arch. In this study it was found that the greater the bowing in of the tendon the flatter the arch. An extreme case showed the tendon of Achilles bowing in nine-tenths of an inch from the perpendicular.

The method used in examining feet by the pedograph was the same as that so ably described in an article by H. Harrison Clarke[1] of Syracuse University.

The correlation coefficients were determined between the two subjective examiners, between each of the instruments, and between each of the instruments and the examiners.

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[1] Clarke, H. Harrison op. cit. p. 105

CHAPTER VIII

FINDINGS AND CONCLUSIONS

The writer feels that for the use of physical educators the pedorule will prove to be as good a measure as any yet found to classify his students into activity groups as far as the status of the feet is concerned.

A very fine example of the low arch type of foot was found in one of the cases in this study. He was a Negro boy, whose footprint angle was eleven degrees for both feet. Both subjective examiners placed his feet in group five, the extreme flat group. His pedorule examination showed zero for both feet. Since there was such a wide disagreement between the results, the writer called the subject into conference for questioning. It was learned he believed he had fallen arches because he had always been told that he had. It was also found that he had never suffered any pains in his feet, legs, or back that could possibly be attributed to flat feet.

The other extreme was a boy whose footprint angle was forty-two. One subjective expert gave him a rating of

"l" while the other classified him in the second group. His pedorule classification was five-tenths for his right foot and four-tenths for his left. Again, such a marked difference brought this subject to the special notice of the writer. He was asked if he ever had any trouble with his feet, whereupon he replied that he could not take hikes, or play basketball, or stand on his feet very long at a time, because of severe pains in his feet, legs, and back. When asked if he ever had headaches he replied, "Yes, very often." These two cases were inserted into this thesis merely to show that by means of the pedorule conditions can sometimes be discovered which would otherwise remain undiscovered.

It has sometimes been suggested that to measure both feet of an individual is a waste of time. It was found in this study that an average of a large group of feet would show the results not differing much, two or three points, but it was also found that in some cases the right foot might be very flat while the left foot was nearly perfect and vice versa. It is readily seen that such a procedure as suggested, measuring only one foot, would be a very unfair and inaccurate thing to do.

The reliability coefficient of the pedorule was found to be .94. The writer feels confident that after many examinations with this instrument the correlation coefficient would be raised considerably.

It was found that a relatively high correlation existed between the subjective examiners and the pedograph. The reason for this is quite apparent. The subjective examiners look at the arch itself and at a glance can see whether or not it is flat, or nearly so. Since the pedograph measures the imprint there is naturally a high correlation between the two.

The correlation coefficient between subjective examiner two and the pedorule was .34. He judged the height of the arch in his examination. The correlation coefficient between examiner one and the pedorule was .38. The fact examiner one included the tendon of Achilles in his examination accounts for his higher correlation with the pedorule. The writer feels that the correlation coefficient between the pedorule and the pedograph was low (.30) because the two instruments were not measuring exactly the same thing.

A Careful examination by the pedorule required forty-five seconds for each subject or about twenty seconds for each foot.. The approximate cost of making one's own instrument should not exceed fifteen cents.

Classification of students' feet for individual physical education can be made more accurately by this instrument than any other, because it really measures what we intend it to measure.

The pedorule, in measuring the deflection of the tendon od Achilles from the perpendicular, does not measure the height of the arch. We are not concerned with the height of the arch if the tendon is perpendicular, because this is the sign of a normal arch. If it is not perpendicular we, as physical educators, have a duty to perform, namely, to strengthen the muscles of the foot to the point where the arch is held in a normal position once more and the tendon no longer bows inward.

SCATTERGRAMS

Correlation of Subjective Examiner Two and Pedorule-r .34

Pedorule

		0	1	2	3	4	5	6	7	8	9	f	d	fd	fd²	+	-
	5	3	1		2	2	2					10	2	-20	40	24	14
Examiner	4	3	5	3	5	3	4				1	24	1	-24	24	23	6
Two	3	18	10	6	4	5	2	1				46					
	2	13	8	12	1		1					35	1	35	35	34	4
	1	3										3	2	6	12	12	0
	f	40	24	21	12	10	9	1	0	0	1						
	d	2	1		1	2	3	4	5	6	7						
	fd	80	24		-12	-20	-27	-4	0	0	-7						
	fd²	160	24		12	40	81	16	0	0	49						

$Cx = \frac{3}{118} = .0254$

$C^2x = .0006$

$\sigma = \sqrt{\frac{111}{118} - .0006}$

$\sigma = .97$

$Cy = \frac{34}{118} = .288$

$C^2y = .083$

$\sigma = \sqrt{\frac{382}{118} - .083}$

$\sigma = 1.77$

$$r = \frac{\frac{69}{118} - .0254 \cdot .288}{.97 \cdot 1.77}$$

$r = .34$

P. I. = .0596

Correlation of Subjective Examiner One and Pedorule- r .38

Pedorule

Examiner One		0	1	2	3	4	5	6	7	8	9	f	d	fd	fd²	+	-
	5	1	2	2	3	1	4	1				14	2	-28	56	64	2
	4	6	8	5	5	2	4				1	31	1	-31	31	45	6
	3	18	8	10	2	6	1					45					
	2	11	4	6	1	1	1					24	1	24	24	11	15
	1	2	1		1							4	2	8	16	4	4
	f	38	23	23	12	10	10	1	0	0	1						
	d	1		1	2	3	4	5	6	7	8						
	fd	38		23	24	30	40	5	0	0	8						
	fd²	38		23	48	90	160	25	0	0	64						

$Cx = \frac{27}{118} = .228$

$C^2x = .052$

$\sigma = \sqrt{\frac{127}{118} - .052}$

$\sigma = 1.011$

$Cy = \frac{92}{118} = .779$

$C^2y = .6068$

$\sigma = \sqrt{\frac{410}{118} - .6068}$

$\sigma = 1.7$

$$r = \frac{\frac{97}{118} - .228 \;.\; .779}{1.011 \;.\; 1.7}$$

$r = .38$

P. I. = .0751

Correlation of Subjective Examiner One and Pedograph- r .54

		Examiner	One									
		5	4	3	2	1	f	d	fd	fd²	+	-
	65-69				2		2	6	12	72	12	0
	60-64						0	5	0	0	0	0
	55-59		2	2	1	1	6	4	24	96	12	8
	50-54	1	1	6	3		11	3	33	99	9	9
	45-49		6	6	5	1	18	2	36	72	14	12
	40-44		1	12	2	3	18	1	18	18	8	1
Pedograph	35-39		6	13	5		24					
	30-34		1	4	5	1	11	1	-11	11	1	7
	25-29	1	3	2			6	2	-12	24	10	0
	20-24	2	3				5	3	-15	45	21	0
	15-19		2				2	4	± 8	32	8	0
	10-14	3	3	2			8	5	-40	200	45	0
	5--9	3	1				4	6	-24	144	42	0
	0--4	3					3	7	-21	147	42	0
	f	13	29	47	23	6						
	d	2	1		1	2						
	fd	-26	-29		23	12						
	fd²	52	29		23	24						

P. I. = .1584

$Cx = \frac{8}{118} = .067$

$C^2x = .0045$

$\sigma = \sqrt{\frac{960}{118} - .0045}$

$\sigma = 2.85$

$Cy = \frac{20}{118} = .1694$

$C^2y = .0287$

$\sigma = \sqrt{\frac{128}{118} - .0287}$

$\sigma = 1.027$

$$r = \frac{\frac{187}{118} - .067 \cdot .1694}{2.85 \cdot 1.027}$$

$r = .54$

Correlation of Subjective Examiners One and Two .58

One

	1	2	3	4	5	f	d	fd	fd²	+	-
Two-5				4	5	10	2	-20	40	28	0
4		2	5	12	5	24	1	-24	24	22	2
3		10	22	11	3	46					
2	3	11	17	4	0	35	1	35	35	17	4
1	1	1	1			3	2	6	12	6	0
f	4	24	46	31	13						
d	2	1		1	2						
fd	8	24		-31	-26						
fd²	16	24		31	52						

$Cx = \frac{3}{118} = .0254$

$C^2x = .0006$

$\sigma = \sqrt{\frac{111}{118} - .0006}$

$\sigma = .97$

$Cy = \frac{25}{118} = .211$

$C^2y = .0445$

$\sigma = \sqrt{\frac{123}{118} - .0445}$

$\sigma = 1.$

$$r = \frac{\frac{67}{118} - .0254 \cdot .211}{.97 \cdot 1.}$$

$r = .58$

P. I. = .1854

Correlation of the Pedorule and Pedograph r .30

Pedorule

		9	8	7	6	5	4	3	2	1	0	f	d	fd	fd'	+	-
	65-69									1	1	2	6	12	72	18	0
	60-64											0	5	0	0	0	0
	55-59									4	2	6	4	24	96	32	0
	50-54							2	4	2	3	11	3	33	99	24	6
	45-49					1	1		5	4	8	19	2	38	76	40	10
	40-44						2	2	4	3	7	18	1	18	18	17	6
Pedograph	35-39	1				2	2	2	2	3	10	22					
	30-34						2	2	2	3	3	12	1	-12	12	6	9
	25-29									3	3	6	2	-12	24	0	18
	20-24						1	2	2	1		6	3	-18	54	12	3
	15-19								1	1	1	3	4	-12	48	0	12
	10-14					3		1	1		2	7	5	-35	175	50	20
	5--9				1		1	1		1		4	6	-24	144	42	6
	0--4				1	1						2	7	-42	294	49	0
	f	1	0	0	2	7	9	12	21	26	40						
	d	7	6	5	4	3	2	1		1	2						
	fd	-7	0	0	-8	-21	-9	-12		26	80						
	fd'	49	0	0	32	63	18	12		26	160						

$Cx = \frac{30}{118} = .254$

$Cy = \frac{49}{118} = .415$

$C^2x = .0645$

$\sigma = \sqrt{\frac{1112}{118} - .0645}$

$\sigma = 3.059$

$C^2y = .172$

$\sigma = \sqrt{\frac{360}{118} - .172}$

$\sigma = 1.7$

$$r = \frac{\frac{200}{118} - .254 \ . \ .415}{3.059 \ . \ 1.7}$$

$r = .30$

P. I. = .0461

Correlation of Subjective Examiner Two and Pedograph- r .50

Examiner Two

		5	4	3	2	1	f	d	fd	fd^2	+	-
	65-69			1	1		2	6	12	72	6	0
	60-64						0	5	0	0	0	0
	55-59			2	3		5	4	20	80	12	0
	50-54		1	4	6		11	3	33	99	18	3
	45-49		2	8	7	1	18	2	36	72	18	4
	40-44	1	1	9	8		19	1	19	19	8	3
Pedo-graph	35-39	1	3	9	7	2	22					
	30-34		5	4	2	1	12	1	-12	12	5	4
	25-29	1	2	3		1	7	2	-14	28	8	4
	20-24		3	1	1	0	5	3	-15	45	9	3
	15-19	2		1			3	4	-12	48	16	0
	10-14	1	4	2			7	5	-35	175	30	0
	5--9	2	1	1			4	6	-24	144	30	0
	0--4	2		1			3	7	-21	147	28	0
	f	10	22	46	35	5						
	d	2	1		1	2						
	fd	-20	-22		35	10						
	fd^2	40	22		35	20						

$Cx = \frac{13}{118} = .1101$

$C^2x = .012$

$\sigma = \sqrt{\frac{941}{118} - .012}$

$\sigma = 2.82$

$Cy = \frac{3}{118} = .0254$

$C^2y = .0006$

$\sigma = \sqrt{\frac{117}{118} - .0006}$

$\sigma = .99$

$$r = \frac{\frac{167}{118} - .1101 \,.\, .0254}{2.82 \,.\, .99}$$

r = .50

P. I. = .1340

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